Preliminary Requirements for P1, P2, AP1, AP3, A1 Beam line BPM Upgrades

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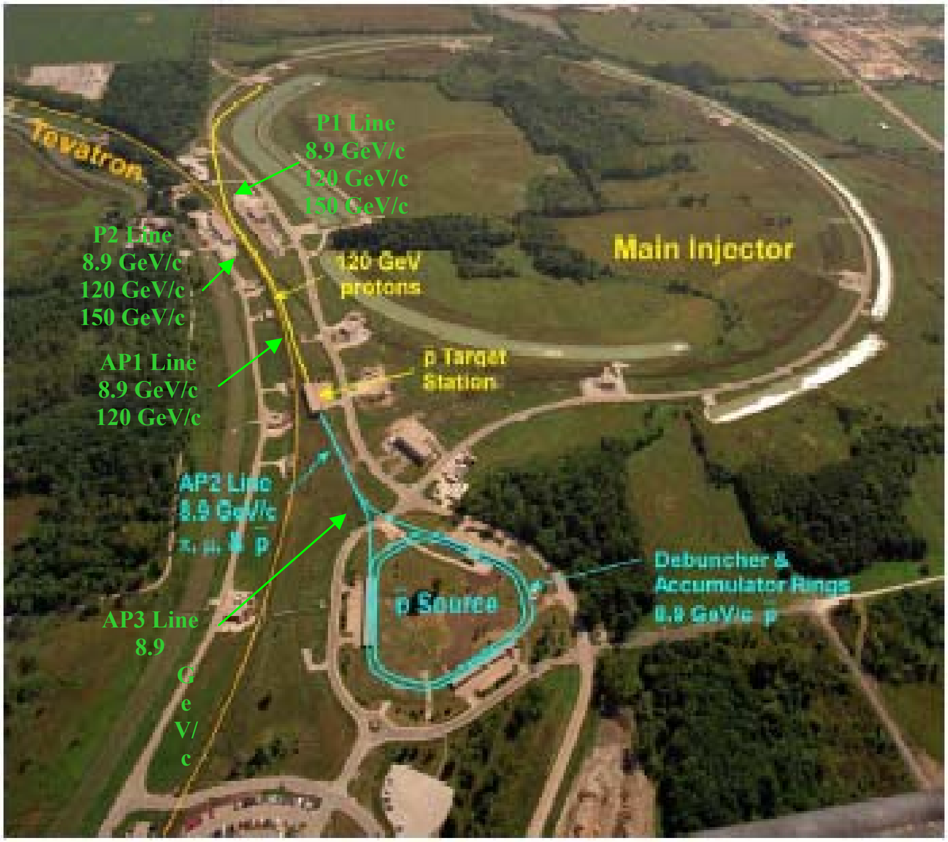
Introduction

By way of introduction, the P1, P2, AP1, and AP3 beamlines comprise the transport section between the Main Injector and the antiproton Accumulator. The A1 line is used to transfer beam from the Main Injector to Tevatron. 87 pickups currently exist Depending upon the collider operations each of these lines transport of variety of beam conditions. The upgraded BPMs are expected to provide position and intensity measurements in each mode of operation and beam condition. This upgrade will replace the current electronics and the data acquisition system between the BPM pickup plates and the controls system. Currently the pickups, electronics, and controls interface for these beam lines are of different vintages and vary in architecture. With that in mind, the goals of this upgrade are to provide BPM data for all foreseen beam conditions with enhanced functionality, better resolution and accuracy from a consistent platform.

The purpose of this document is to lay out the requirements needed as a basis for the technical design and specifications for the upgraded Beam line BPM system. As work progresses on this effort, modifications to the requirements may be necessary and will be incorporated into future versions of this document.

Scope of the Project

The scope of the BPM upgrade includes everything necessary to measure beam positions and intensities for operation of the transfer lines involved with the transport of bunched antiproton beams, specifically the A1, P1, P2, AP1, & AP3 beam lines. The upgrade will make use of the existing split-plate pickups. It does include electronics and software necessary to make position and intensity measurements for each beam mode during normal operations. This includes diagnostics for maintaining and calibrating the new system but does not include end user applications such as orbit recording or lattice measurement software. Also included is relevant documentation, manuals, user guides, and any other documentation necessary to upgrade and maintain the system. In short, this upgrade will provide all of the necessary hardware and software so that the end user may measure the beam position and intensity of particles traversing these lines regardless of intensity, bunch structure, direction, and particle type.



Beam Modes

The transfer lines in question operate in five different modes of operation: Reverse Protons, Antiproton transfers, Antiproton stacking, Switchyard 120, and Tevatron transfers. Each are described below. Other modes are possible, but are infrequently used and BPM requirements fit within the purview of these modes.

Reverse Protons refers to sending bunches of 8 GeV protons from the Main Injector to the Accumulator. This mode is used to tune up the transfer lines used to transport antiprotons from the Accumulator to Main Injector as well as for high intensity beam studies of the Antiproton source complex as Pbars cannot be seen with the current set up of the BPM system. While this role will diminish in the Frequent Transfers era, where BPM data with Pbars is required, it will still be necessary to support BPM's in this mode. The beam conditions are defined in the table below.

Beam Type	8 GeV protons
Bunch RF	53 MHz
Bunch Structure	7 to 84 consecutive bunches
Min Intensity per Bunch	2.5 E9
Max Intensity per Bunch	15 E9
Beam Lines	P1,P2,AP1,AP3

The Antiproton transfer mode refers to any transfer of 8 GeV antiprotons from the Accumulator to the Main Injector and beyond (Recycler or Tevatron). In the Frequent Transfers era these transfers will occur approximately every 15 - 30 minutes. Orbits generated by these transfers will be the one of the primary means to monitor the performance of the antiproton transfer lines in this mode. The beam conditions are defined in the table below.

Beam Type	8 GeV antiprotons
Bunch RF	2.5 MHz
Bunch Structure	4 bunches
Min Intensity per Bunch	2.5 E9
Max Intensity per Bunch	30 E9
Beam Lines	P1,P2,AP1,AP3

The Stacking mode refers to transporting 120 GeV protons from the Main Injector to the antiproton production target station. These transfers occur approximately every couple seconds. The beam conditions are defined in the table below.

Beam Type	120 GeV protons
Bunch RF	53 MHz
Bunch Structure	84 consecutive bunches
Min Intensity per Bunch	2.5 E9
Max Intensity per Bunch	100 E9
Beam Lines	P1,P2,AP1

The Switchyard 120 (SY120) mode is used to transfer protons from the Main Injector down to the Fixed Target experimental areas. In this case beam transfer occurs from a slow spill out of the Main Injector and can be 0.5 to 1.0 second in length. The beam conditions for SY120 operation are listed below.

Beam Type	120 GeV protons
Bunch RF	53 MHz
Bunch Structure	>1e6 consecutive bunches
Min Intensity per Bunch	4.5 E3
Max Intensity per Bunch	40 E3
Beam Lines	P1,P2

Finally the Tevatron transfer mode involves several methods to transfer both protons and antiprotons beam between the Main Injector and Tevatron. In the case of protons, these transfers can occur with either a single coalesced bunch or a number of consecutive (uncoalesced) bunches going in either direction during tuneup. For antiprotons four bunches are transferred from the Main Injector to the Tevatron.

Beam Type	150 GeV protons
Bunch RF	53 MHz
Bunch Structure	Single coalesced or up to 84 Consecutive bunches
Min Intensity per Bunch	(???)
Max Intensity per Bunch	(???)
Beam Lines	P1, A1

Beam Type	150 GeV antiprotons
Bunch RF	53 MHz
Bunch Structure	4 bunches at 2.5 MHz
Min Intensity per Bunch	2.5 E9
Max Intensity per Bunch	35 E9
Beam Lines	A1

The table below summarizes the expected modes of operation and beam conditions by beam line. Beam conditions, structure and intensity, are for typical operation.

Mode	**Beam line**	**Energy (GeV)**	**Particle**	**Bunch structure**	**Intensity**	**Read frequency**
Reverse protons	P1	8	Protons	53 MHz up to 84 bunches	10^{11}	.1 Hz or less
Pbars to MI/RR/Tevatron	P1	8	Pbars	4 bunches of 2.5 MHz superimposed on 53 MHz	10^{10} – 10^{11}	.1 Hz or less
Stacking	P1	120	protons	53 MHz up to 84 bunches	10^{13}	~.5 Hz
SY120	P1	120	protons – slow spill	53 MHz	10^{11}	.5 – 1 sec spill
Collider protons	P1	150	Protons	single coalesced bunch	10^{12}	
Reverse protons	P2	8	Protons	53 MHz – up to 84 bunches	10^{11}	.1 Hz or less
Pbars to MI/RR/Tevatron	P2	8	Pbars	4 bunches of 2.5 MHz superimposed on 53 MHz	10^{10} – 10^{11}	.1 Hz or less
Stacking	P2	120	Protons	53 MHz up to	10^{13}	~.5 Hz

				84 bunches		
SY120	P2	120	protons – slow spill	53 MHz	10^{11}	.5 – 1 sec spill
Reverse protons	AP1	8	Protons	53 MHz up to 84 bunches	10^{11}	.1Hz or less
Pbars to MI/RR/Tevatron	AP1	8	Pbars	4 bunches of 2.5 MHz superimposed on 53 MHz	10^{10} – 10^{11}	.1 Hz or less
Stacking	AP1	120	Protons	53 MHz up to 84 bunches	10^{13}	~.5 Hz
Reverse protons	AP3	8	Protons	53 MHz up to 84 bunches	10^{11}	.1Hz or less
Pbars to MI/RR/Tevatron	AP3	8	Pbars	4 bunches of 2.5 MHz superimposed on 53 MHz	10^{10} – 10^{11}	.1 Hz or less
Collider tuneup – protons from Tevatron to MI	A1	150	protons (from Tevatron to MI)	53 MHZ up to 84 bunches single coalesced bunch	10^{10} - 10^{11}	
Pbars from MI to Tevatron	A1	150	Pbars	2.5 MHz up to 4 bunches	10^{10} – 10^{11}	.5 Hz?

Measurement Specifications

The upgraded BPM system will provide position measurements for each of the beam operating modes listed above. The position accuracy is how well the position of the beam relative to the device being used to measure it can be determined. This is limited by a number of factors including alignment, calibration, cable attenuation and noise, as well as signal processing. The position resolution differs from accuracy in that it refers to how well small displacements of the beam can be measured. For this project the good resolution is much more important than good accuracy. While it is recognized that there should be an accuracy specification, it is premature to document one. The table below lists what the measurement will be used for in each mode and the requirements on that measurement.

Mode	Use	Position Accuracy	Position Resolution	Frequency of Measurement
Reverse Protons	Monitor & Tune-up	TBD	0.25 mm	0.1 Hz
Antiproton Transfer	Monitor	TBD	0.25 mm	0.1 Hz
Stacking	Monitor	TBD	0.25 mm	0.7 Hz
SY120	Monitor	TBD	0.25 mm	1/min
Tevatron Transfer	Monitor & Tune-up	TBD	0.25 mm	0.1 Hz

The upgrade is primarily motivated by 'Frequent' Transfers of Pbars from the Accumulator to the MI, but all other beam operations should be factored into the upgrade. As opposed to using reverse protons to ensure the beam lines are tuned up before pbars are transferred, the feedback mechanism to tune up the line will be previous antiproton transfers. Data will need to be gathered automatically (SDA) and available to beam line tuning applications. It will still be necessary to support 'real-time' data gathering with reverse protons for studies/large-scale tune up opportunities.

The implementation will need to take into account that switching modes of operation can occur within the same supercycle (seconds) and that there are clock events, and possibly state devices in the future, which will define a data gathering mode. The switch must be seamless and it must be obvious on which cycle a particular orbit is gathered. Also implied is that a subset of all beam lines may gather data simultaneously, but not necessarily e.g. P1, P2, AP1 will operate together for stacking cycles, AP3, AP1, P2, P1 for antiproton transfers, and P1, P2 (and P3) for SY120.

Data Acquisition

The upgraded BPM system will be expected to provide position and intensity measurements to the Accelerator Controls system for each traversal of beam through the given transport lines. While the ability to buffer this data in the front-end exists, it is not expected to be necessary given the timing between beam pulses. The data will be used to feed user applications such as orbit or lattice measurements or fast time plots. Applications currently in use employ reverse proton orbits to tune up the transfer lines for maximum efficiency. With antiproton transfers expected to occur every 15 to 30 minutes and take more than a minute each, it will be critical to feed Pbar BPM data into an application for regular monitoring and tuning of the lines.

The timing component of acquiring the data is expected to be a mixture of hardware and software. The system will be armed and setup for a particular beam mode by either a TCLK event or an ACNET state device. During beam transport, a hardware trigger will be generated off of the related BSCLK events. This will acquire data in a large enough window that the beam signal is assured to appear. Front-end software will then extract the beam signal from this data for the position and intensity measurement. A user controlled trigger will also be supported for testing and diagnostic purposes.